

## Cranial Growth in *Saimiri sciureus* (Cebidae) and Its Alteration by Nutritional Factors: A Longitudinal Study

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**ABSTRACT** Ten male *Saimiri sciureus boliviensis* (Cebidae), born at the Centro Argentino de Primates (CAPRIM), were grown in captivity. At weaning (6 months old), five individuals were fed ad libitum on a 20% protein diet (controls). The other five animals were fed ad libitum on a 5% protein diet (malnourished). Animals were radiographed monthly. The length, width, and height of the anterior, middle, and posterior components of the neurocranium, and those of the masticatory, respiratory, and optic components of the face were measured. A pattern of high growth rate was observed in both the three facial and the middle neural components. The anterior and posterior neural components showed a pattern of low rate of growth. The growth behavior of each variable was also different. Lengths grew more than widths and heights in the facial components, whereas widths grew more than heights and lengths in the neurocranium. Malnutrition delayed growth in size and altered the normal shape changes. High-patterned variables, such as masticatory and respiratory lengths, and the anterior and middle neural widths were particularly affected. The masticatory and the middle neural components underwent the greatest growth arrest. The optic and the respiratory components suffered a mild effect. The anterior and the posterior neural components were affected to a lesser degree. Am J Phys Anthropol 102:545-554, 1997.

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The craniofacial structure of platyrrhine monkeys resembles that of the Old World nonhuman primates in several ways. Some authors (Schultz, 1962; Petit-Maire, 1971) believe that human-like traits of the skull are greater in cebids than in cercopithecids. This resemblance is particularly close in the genus *Saimiri*. Ameghino (1909) and Biegert (1963) pointed out a number of commonalities between *Homo* and *Saimiri*. The similarity suggests that this monkey is a good model for experimental studies about human growth and development.

Functional cranial theory (Klaauw, 1948-52; Moss and Young, 1960; Moss, 1973) states that craniofacial development needs to be interpreted in terms of changes be-

tween minor functional cranial components (FCC). This theory essentially presupposes that skeletal growth may vary in response to mechanical stresses and the demands of the functionally associated soft tissues and cavities which also grow. The FCCs behave relatively independently in the growth process. They are integrated by a functional matrix (FM), and a skeletogen

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unity (SKU) which gives biomechanical support an protection to the FM demands (Moss, 1979).

Several studies performed on the cranial anatomy of the *Saimiri* genus (Delattre and Anthony, 1951; Hill, 1960; Thom, 1965; Hershkovitz, 1977; Kaack et al., 1979; Ayres, 1985; Thorington, 1985; Pucciarelli et al., 1990; Dressino, 1991; Corner and Richtsmeier, 1992; Hartwig, 1995; Pucciarelli and Dressino, 1996) described the behavior of cranial structures during growth. Some aspects, however, are not well known. One of them is the behavior of minor cranial components during growth in both normal and stressed environments. The present study fills that gap. The aim here is: (1) to describe the growth of the masticatory, the respiratory and the optic components of the splanchnocranium, and the growth of the anterior, the middle and the posterior components of the neurocranium; and (2) to measure the extent to which the growth of each facial and neurocranial functional component was inhibited when animals were fed on a low-protein diet.

## MATERIALS AND METHODS

Ten male *Saimiri sciureus boliviensis* (Cebidae) were employed. They were born at the Centro Argentino de Primates (CAPRIM). After weaning (6 months of age), the animals were raised at the Facultad de Ciencias Médicas of the Universidad Nacional de La Plata. On weaning, the animals were divided in two groups. Five controls (C) were fed ad libitum on a 20% protein diet. Five malnourished (M) were fed ad libitum on a 5% protein diet (Table 1). The amount of protein in the feed for the malnourished group was reduced gradually (5% weekly for three weeks) to minimize stress induced by sudden dietary change.

Cranial components were measured on vertical and lateral radiographs. They were taken every 30 days, with a Siemens apparatus (Focus film distance: 1.2 m; exposition: 100 mA; 0.02 seg.; 40–50Kw). Each monkey was anesthetized with 0.01 ml/g of Ketalar (Parke Davis), and fixed to a 90

TABLE 1. Percent composition of control and low-protein diets

Component	Control amount (g)	Protein content (g)	Low-protein amount (g)	Protein content (g)
Soybean meal	28.0	13.0	1.5	0.6
Wheat meal	14.7	1.8	14.7	1.8
Rice meal	3.3	0.3	8.2	0.8
Wheat bran	5.6	1.0	5.6	1.0
Corn starch	3.0	0.0	30.0	0.0
Sugar	3.5	0.0	3.5	0.0
Skimmed milk	10.6	3.7	2.1	0.7
Egg	7.0	0.2	1.3	0.1
Margarine	4.2	0.0	7.9	0.0
Vitamin mixture	1.4	0.0	1.4	0.0
Salt mixture	1.4	0.0	1.4	0.0
Water	17.3	0.0	22.4	0.0
Total	100.0	20.0	100.0	5.0

degree rotating cephalostat. The measurements were begun when the monkeys were 9 months old and were continued throughout the 2 years of the experimental period.

The length (L), width (W), and height (H) of cranial components were measured as follows: *masticatory component*: ML, from midpoint between gonions to midpoint between the lower incisors; MW, distance between gonions; MH, from midpoint between the upper incisors to gnathion; *Respiratory component*: RL, from nasal-alveolar point to nasal-orbital angle; RW, distance between the two upper diastemas; RH, distance from nasal-alveolar point to rhinion; *Optic component*: OL, from the optic foramen to midpoint at the maximum orbit breadth; OW, maximum orbit breadth; OH, distance from the orbital-frontal angle to the orbital-nasal one; *Anterior neural component*: ANL, from the orbital-frontal angle to the midpoint at the distance between optic foramen-frontal inflection; ANW, postorbital cranial width; ANH, from optic foramen to the frontal inflection; *Middle neural component*: MNL, from the orbital-nasal angle to basion; MNW, eurion-eurion distance; MNH, basion-bregma distance; *Posterior neural component*: PNL, lambda-opisthion length; PNW, width just over the vermion point; PNH, distance from vermion to the parietal inflection (Figs. 1, 2).

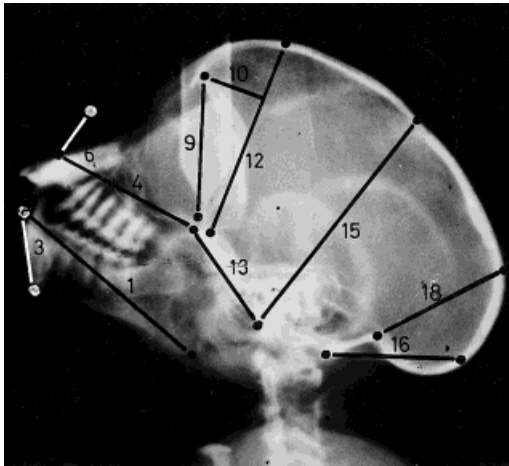


Fig. 1. Cranial radiograph in lateral view. 1, masticatory length; 3, masticatory height; 4, respiratory length; 6, respiratory height; 9, optic height; 10, anterior neural length; 12, anterior neural height; 13, middle neural length; 15, middle neural height; 16, posterior neural length; 18, posterior neural height.

The radiographic magnification coefficient (MgC) and the radiographic distortion index (DsI) were calculated as follows:

$$\text{MgC} = B_x/A_x$$

$$\text{DsI} = 100 \sqrt{(A_x/A_y - B_x/B_y)^2}$$

where:

$A_1$  = incisor-inion length measured  
on radiographs;

$A_2$  = bi-ectochonchial width measured  
on radiographs;

$A_3$  = basion-bregma height measured  
on radiographs;

$B_1$  = incisor-inion length measured  
on skull;

$B_2$  = bi-ectochonchial width measured  
on skull;

$B_3$  = basion-bregma height measured  
on skull.

Dahlberg's error of the method (Se) and reliability coefficient (RC; Bresin et al., 1994) for all variables were calculated. To do this, two radiographic series belonging to animals of the same age were employed.

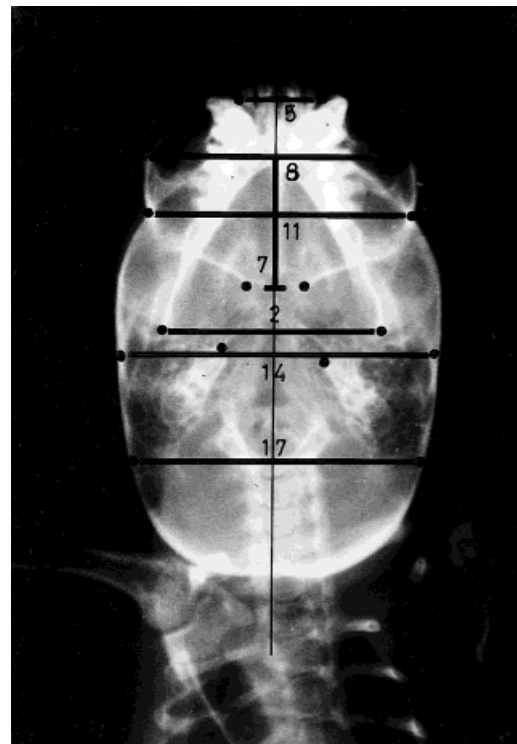


Fig. 2. Cranial radiograph in vertical view. 2, masticatory width; 5, respiratory width; 7, optic length; 8, optic width; 11, anterior neural width; 14, middle neural width; 17, posterior neural width.

$$\text{Se} = \sqrt{\sum d^2/2n}$$

$$\text{RC} = (1 - \text{Se}^2/\text{St}^2)100$$

where:

$d$  = difference between the pairs  
measured

$n$  = sample size

$\text{St}$  = the total variance of the  
measurement.

Correlation coefficients ( $r$ ) between each variable and chronological age were also calculated. They indicate the degree to which the independent variable (chronological age) covaries with each metric one (dependent variable). Correlation  $t$ -tests ( $t_r$ ) gave the probability level ( $P$ ) of the " $r$ " correlation values. When they were signifi-

cant ( $P < 0.05$ ) or highly significant ( $P < 0.01$ ), simple lineal regressions were calculated, using the intercept (a) and the slope (b) parameters. Probability levels of  $t_a$  and  $t_b$ , and of the validity of the model, ( $F_m$ ), were also measured. All statistics were made by the ARGSTAD package, at the Centro de Investigaciones en Genética Básica y Aplicada (CIGEBA).

## RESULTS

### Error of method

According to the magnification coefficients, the lengths, widths, and heights measured on the radiographs have to be multiplied by 0.94, 0.95 and 0.92, respectively, to obtain the actual cranial values. Distortion indices for the lateral and vertical views were 2.4% and 2.0%, respectively. The radiographic bias was always less than 3.0%.

The error of the method (Se) varied in the controls from 0.23 for masticatory width to 0.93 for respiratory length. Se varied from 0.15 for masticatory length to 1.48 for respiratory width in the malnourished animals. The reliability coefficient varied between 84.3% (anterior neural height) and 99.9% (middle neural height and posterior neural width) in the controls. In malnourished animals, it ranged between 80.1% (optic height) and 99.9% (masticatory width, anterior neural width, and posterior neural length and height; Table 2).

### Correlation and regression

Masticatory length, width and height, respiratory length, optic length and width, and anterior and middle neural widths and heights were highly correlated ( $P < 0.01$ ) with age in control animals (Tables 3, 5). Significant values ( $P < 0.05$ ) were observed for respiratory width and height, optic height, middle neural length and posterior neural width and height. The anterior and the posterior neural lengths were uncorrelated with age.

Regression coefficients (Tables 3, 5; Figs. 3–5) were highly significant for masticatory length, width and height; respiratory length, width and height; optic length, width and height; anterior neural width and height; middle neural length, width, and height;

TABLE 2. Error of the method (Se) and reliability coefficient (RC) for the measurements

Measurement	Controls		Malnourished	
	Se	RC (%)	Se	RC (%)
Masticatory length	0.34	99.8	0.56	99.8
Masticatory width	0.23	99.8	0.33	99.9
Masticatory height	0.40	98.5	0.15	88.3
Respiratory length	0.93	97.2	0.37	97.3
Respiratory width	0.45	98.4	1.48	99.6
Respiratory height	0.54	93.8	0.51	97.1
Optic length	0.34	98.9	0.54	99.7
Optic width	0.39	97.0	0.39	99.8
Optic height	0.37	98.5	0.22	80.1
Anterior neural length	0.55	99.7	0.38	99.7
Anterior neural width	0.55	99.8	0.24	99.9
Anterior neural height	0.39	84.3	0.72	96.0
Middle neural length	0.75	99.2	1.16	98.4
Middle neural width	0.24	99.8	0.61	99.3
Middle neural height	0.42	99.9	0.55	99.2
Posterior neural length	0.61	99.7	0.67	99.9
Posterior neural width	0.27	99.9	0.40	99.8
Posterior neural height	0.55	99.6	0.64	99.9

TABLE 3. Correlation (r) and linear regression (a, b) coefficients for the averaged variable values versus age in controls

Measurement	r	a	b
Masticatory length	0.98	28.07	6.9E-3
Masticatory width	0.93	23.42	3.6E-3
Masticatory height	0.83	11.89	1.7E-3
Respiratory length	0.90	18.00	4.2E-3
Respiratory width	0.68	9.41	1.6E-3
Respiratory height	0.75	5.17	1.6E-3
Optic length	0.80	13.56	1.7E-3
Optic width	0.98	28.30	6.0E-3
Optic height	0.69	18.44	1.1E-3
Anterior neural length	0.35	—	—
Anterior neural width	0.93	27.58	3.3E-3
Anterior neural height	0.88	24.23	2.3E-3
Middle neural length	0.70	14.03	2.5E-3
Middle neural width	0.89	34.31	4.4E-3
Middle neural height	0.78	33.42	2.5E-3
Posterior neural length	0.02	—	—
Posterior neural width	0.68	32.50	3.9E-3
Posterior neural height	0.56	19.80	1.5E-3

and posterior neural width. A significant regression coefficient was found for the posterior neural height.

In malnourished animals (Tables 4, 6), highly significant correlations with age were obtained for masticatory and respiratory lengths, optic, middle and posterior neural widths; and optic height. There were significant correlations with age for masticatory height; respiratory width and anterior neural width and height. Masticatory width, respiratory height, optic length, anterior, middle and posterior neural lengths, and

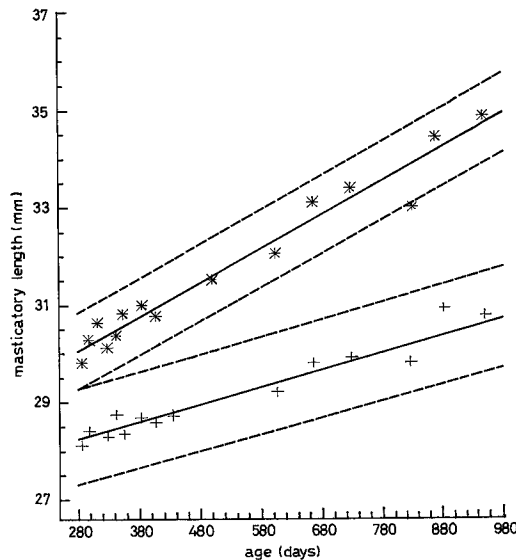


Fig. 3. Lineal regression tests for the masticatory length in control (asterisks) and malnourished (crosses) groups.

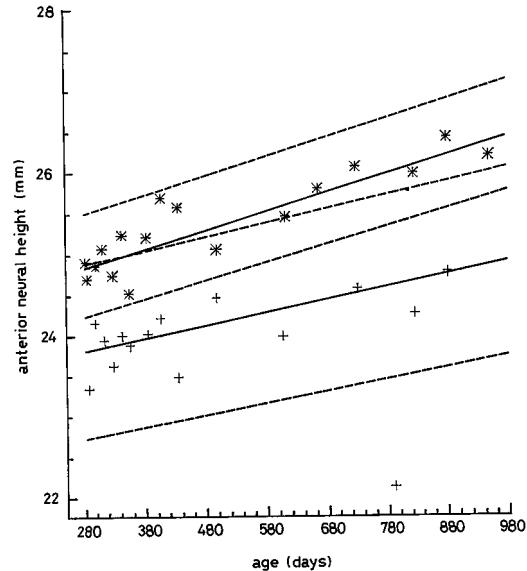


Fig. 5. Lineal regression tests for the anterior neural height in control (asterisks) and malnourished (crosses) groups.

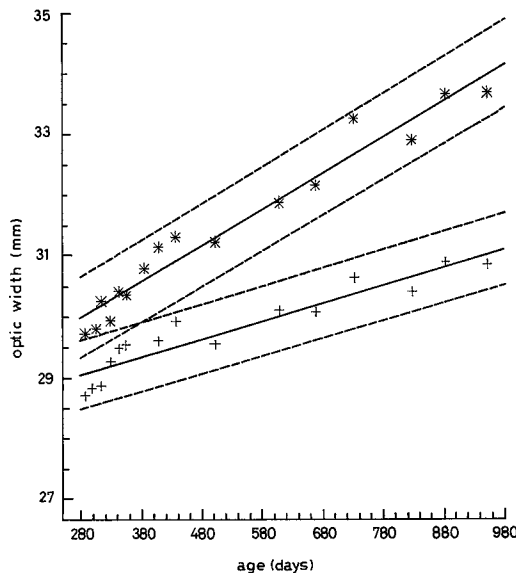


Fig. 4. Lineal regression tests for the optic width in control (asterisks) and malnourished (crosses) groups.

middle, and posterior neural heights were uncorrelated with age.

Regression coefficients (Tables 4, 6; Figs. 3-5) were highly significant for masticatory and respiratory lengths, respiratory, optic,

and anterior, middle, and posterior neural widths, and masticatory, and optic heights. A significant regression coefficient was found for the anterior neural height. Pooled values from residuals showed even dispersions in the facial and in the anterior neural variables. They were lower than that of the middle and the posterior neural ones. In controls, the lowest range was observed in respiratory height, and the greatest one in the posterior neural width. Malnourished animals showed the lowest range in masticatory height and its greatest one in the posterior neural width (Table 7).

## DISCUSSION

Regression slopes showed that, in general terms, cranial growth in *Saimiri* is well described by the equation  $y = a + bx$  (Tables 3-6; Figs. 3-5). With the exception of posterior neural width, low residual values were observed for the regressions. The averaged regression coefficients for controls indicated that the face grew faster ( $b_x = 0.0032$ ) than the neurocranium ( $b_x = 0.0023$ ). The average of the correlation coefficients indicated that the fraction of variability with age explained by growth was about 70% for the

TABLE 4. *t*-test for correlation ( $t_r$ ) and lineal regression ( $t_a$ ,  $t_b$ ) coefficients and for ANOVA test for model ( $F_m$ ) for the averaged variable values in controls<sup>1</sup>

Variable	$t_r$	$t_a$	$t_b$	$F_m$
Masticatory length	3.79**	128.21**	17.88**	319.73**
Masticatory width	3.60**	109.24**	9.54**	90.91**
Masticatory height	3.22**	71.49**	5.59**	31.29**
Respiratory length	3.49**	60.37**	7.90**	62.40**
Respiratory width	2.64*	35.33**	3.47**	12.05**
Respiratory height	2.91*	23.74**	4.22**	17.78**
Optic length	3.10**	69.06**	4.96**	24.63**
Optic width	3.80**	147.10**	17.59**	309.32**
Optic height	2.67*	102.34**	3.58**	12.83**
Anterior neural length	1.36	—	—	—
Anterior neural width	3.61**	145.98**	9.71**	94.30**
Anterior neural height	3.41**	132.57**	7.00**	48.96**
Middle neural length	2.71*	36.47**	3.68**	13.55**
Middle neural width	3.45**	98.65**	7.10**	50.36**
Middle neural height	3.02**	110.28**	4.66**	21.75**
Posterior neural length	0.08	—	—	—
Posterior neural width	2.64*	49.94**	3.42**	11.70**
Posterior neural height	2.17*	59.92**	2.55*	6.51**

<sup>1</sup> D.F. = 15.\*  $0.01 < P < 0.05$ .\*\*  $P < 0.01$ .

face and 44% for the neurocranium. Consequently, the face grew more, and grew less randomly than the neural portion of the skull. This was in agreement with the hypothesis that face growth is explained by the volumetric expansion of the oro-nasopharyngeal cavity (Moss, 1973). Changes in size and shape were also found for the respiratory spaces and dentition in pongids (Sirianni and Swindler, 1979).

Corner and Richtsmeier (1991) found in *Cebus apella* that growth was largest in the muzzle, intermediate in the upper face, and smallest in the orbit cavities. In the present

TABLE 5. Correlation ( $r$ ) and lineal regression ( $a$ ,  $b$ ) coefficients for the averaged variable values versus age, in malnourished animals

Measurement	$r$	$a$	$b$
Masticatory length	0.88	27.27	3.5E-3
Masticatory width	-0.54	—	—
Masticatory height	0.63	11.82	7.3E-4
Respiratory length	0.85	18.42	2.0E-3
Respiratory width	0.66	8.94	1.6E-3
Respiratory height	0.06	—	—
Optic length	0.53	—	—
Optic width	0.94	28.21	3.0E-3
Optic height	0.85	17.74	1.5E-3
Anterior neural length	0.46	—	—
Anterior neural width	0.74	27.76	1.6E-3
Anterior neural height	0.60	23.38	1.5E-3
Middle neural length	0.11	—	—
Middle neural width	0.93	33.05	2.6E-3
Middle neural height	0.20	—	—
Posterior neural length	-0.37	—	—
Posterior neural width	0.83	30.72	3.4E-3
Posterior neural height	-0.03	—	—

study, the averaged slope values indicate that the masticatory portion of the face grows more than the optic one, and the latter grows slightly more than the respiratory portion. The active growth in the orbit cavities found here correlates well with the greater optic development found in *Saimiri* with respect to *Cebus*.

Similar active masticatory growth findings were reported by Gagliardi and Colillas (1985). The explanation for these observations is linked to the development of the permanent dentition that occurs during this period. Clearly, after childhood the masticatory apparatus follows a common growth pattern in several primate species (Schultz, 1962).

After birth, the brain, which develops earlier than any other structure in mammals, strongly influences neurocranial (Topinard, 1891; Delattre, 1951; Moss and Young, 1960; Delattre and Fenart, 1963; Hofer, 1969; Moss, 1973; Michejda, 1975; Sirianni and Swindler, 1979; Moss et al., 1982; Sirianni, 1985), and orbit (Hartwig, 1995) growth. Slower neurocranial growth with respect to the face as seen in *Saimiri* was also observed in rats (Pucciarelli, 1981; Oyhenart,

TABLE 6. *t*-test for correlation ( $t_r$ ) and linear regression ( $t_a$ ,  $t_b$ ) coefficients and for ANOVA test for model ( $F_m$ ) for the averaged variable values, in malnourished animals<sup>1</sup>

Variable	$t_r$	$t_a$	$t_b$	$F_m$
Masticatory length	3.41**	97.84**	7.06**	49.80**
Masticatory width	-2.09	—	—	—
Masticatory height	2.44*	86.48**	3.03**	9.17**
Respiratory length	3.30**	98.61**	6.14**	37.71**
Respiratory width	2.56*	33.43**	3.29**	10.79**
Respiratory height	0.23	—	—	—
Optic length	2.04	—	—	—
Optic width	3.64**	177.77**	10.60**	112.28**
Optic height	3.30**	132.08**	6.14**	37.72**
Anterior neural length	1.78	—	—	—
Anterior neural width	2.87*	129.42**	4.08**	16.68**
Anterior neural height	2.33*	75.83**	2.83*	8.02**
Middle neural length	0.43	—	—	—
Middle neural width	3.61**	214.81**	9.36**	87.51**
Middle neural height	0.78	—	—	—
Posterior neural length	-1.43	—	—	—
Posterior neural width	3.22**	89.09**	5.56**	30.87**
Posterior neural height	-0.12	—	—	—

<sup>1</sup> D.F. = 15.\* 0.01 <  $P$  < 0.05.\*\*  $P$  < 0.01.

1988) and primates (Schultz, 1962; Pucciarelli et al., 1990; Dressino, 1991; Pucciarelli and Dressino, 1996). The relative differences in growth have been attributed to the longer growth span of the face rather than to growth rate differences, because facial growth ends later than that of the neural mass.

The basicranium is relevant for the growth of the skull in primates (Michejda, 1975; Lestrel and Sirianni, 1982). It grows posteriorly in cercopithecids (Schultz, 1962; Petit-Maire, 1971; Elgoyhen et al., 1972) and platyrrhines (Corner and Richtsmeier, 1991,

TABLE 7. Mean ( $\bar{X}$ ) and standard deviation (S.D.) of pooled values for the residuals from the regression analyses

Variable	Controls		Malnourished	
	$\bar{X}$	S.D.	$\bar{X}$	S.D.
Masticatory length	0.26	0.08	0.28	0.32
Masticatory width	-0.26	0.27	-0.28	-0.29
Masticatory height	0.36	0.32	—	—
Masticatory length	-0.17	0.13	—	—
Respiratory length	0.20	0.10	0.16	0.16
Respiratory width	-0.25	0.11	-0.15	0.10
Respiratory height	0.25	0.22	0.23	0.14
Respiratory length	-0.42	0.40	-0.23	0.16
Respiratory width	0.36	0.27	0.38	0.22
Respiratory height	-0.28	0.21	-0.25	0.28
Optic length	0.20	0.22	—	—
Optic width	-0.21	0.23	—	—
Optic height	0.21	0.14	—	—
Anterior neural length	-0.26	0.22	—	—
Anterior neural width	0.26	0.20	0.18	0.13
Anterior neural height	-0.21	0.12	-0.23	0.09
Middle neural length	0.22	0.17	0.15	0.10
Middle neural width	-0.22	0.12	-0.19	0.10
Middle neural height	0.26	0.24	0.31	0.27
Posterior neural length	-0.33	0.25	-0.52	0.26
Posterior neural width	0.23	0.15	0.28	0.47
Posterior neural height	-0.23	0.15	-0.35	0.17
Middle neural length	0.48	0.25	—	—
Middle neural width	-0.48	0.36	—	—
Middle neural height	0.37	0.32	0.15	0.10
Posterior neural length	-0.48	0.27	-0.25	0.12
Posterior neural width	0.45	0.34	—	—
Posterior neural height	-0.32	0.19	—	—
Posterior neural length	0.82	0.54	0.34	0.24
Posterior neural width	-0.86	0.77	-0.57	0.25
Posterior neural height	0.46	0.36	—	—
Posterior neural length	-0.35	0.20	—	—

1992). Some nonsignificant regressions with age found here indicate, however, a null growth in length for the posterior neural component. This fact can be explained by the globular trend in the growth of the cerebellum and associated structures. Such a trend in *Saimiri* is evoked by active growth in width and height, given that age explained 46% ( $r = 0.68$ ) of the variation in posterior neural width, 31% ( $r = 0.56$ ) of the variation of the posterior neural height, and less than 0.1% ( $r = 0.02$ ) of that of the posterior neural length in these animals.

Two patterns of growth were seen in controls. One of them belongs to the face: the averaged regression slopes for growth in length was the greatest ( $b_x = 0.0043$ ), followed by the width ( $b_x = 0.0037$ ), and height ( $b_x = 0.0015$ ). The other pattern belongs to the neurocranium: growth in width was stronger ( $b_x = 0.0038$ ), than in height ( $b_x = 0.0021$ ), and in length ( $b_x = 0.0008$ ).

Each pattern is related to particular functional demands. The pattern for the face is governed by growth of the alveolar component; hence, the face grows mainly along the anteroposterior axis. Neurocranial shape changes are due to the transverse facial growth evoked by the growing frontal teeth. In order to protect the early developed neural mass, the braincase does not change its volume. This evokes a compensatory decrease in height, but mainly a decrease in length.

Several studies about malnutrition in cercopithecids have been made. Rutenberg and Coelho (1988) reported that different amounts of caloric availability during the neonatal period acted on growth and development. They found changes in body weight and length, and in triceps circumference during infant, juvenile and adolescent periods. Shimizu et al. (1994) evoked a restriction-recuperation process by administering stock diet in different amounts, and in different periods. They found that limbs and trunk were mainly affected, while no head variation was evident. DeRousseau and Reichs (1987) also found that malnutrition affected allometric growth in the primate skeleton. Malnutrition acts on skeletal growth by altering endochondral (Jha et al., 1968) and transverse line (Murchinson et al., 1984) bone formation. Weindruch et al. (1995) varied the energy intake by overfeeding one group of primates and underfeeding the other. They found that the feeding impact on body length and weight and skinfold thickness was greater in Rhesus than in *Saimiri*.

Malnutrition in the present study affected growth of both major cranial components, and particularly the face. The averaged correlation values were 0.23 and 0.32 for the neuro- and the splanchnocranium, respectively. This indicates that under malnutrition, only 10% of face and 5% of neurocranial variability can be explained by growth. Malnutrition arrested more than 50% of the cranial growth, but it kept unchanged the two main patterns of growth. In the splanchnocranium, the averaged regression slopes for lengths was the greatest ( $b_x = 0.0018$ ), followed by those of widths ( $b_x = 0.0015$ ) and heights ( $b_x = 0.0007$ ). In the neurocranium, the averaged regression slopes for

widths and heights ( $b_x = 0.0025$ ), and ( $b_x = 0.0005$ ) were greater than those for the lengths ( $b_x = 0.0001$ ). Reduction in face, however, was not equal to that of the neurocranium (59% and 55%, respectively).

In summary, malnutrition arrests mostly growth in size and secondarily evokes shape changes by altering the relative growth between the two major functional components (neuro- and splanchnocranium). Shape changes are also inferred from the different amounts of size reduction observed between the minor functional components. The masticatory and the middle neural components suffered a great arrest of growth (66% and 72%). The optic and the respiratory components underwent a mild effect (58% and 51%), while the anterior and posterior neural ones were affected in a lesser degree (47% and 37%).

Malnutrition changed masticatory and respiratory lengths, and optic, anterior, and middle neural widths, in the same manner as found in rats (Pucciarelli, 1981) and monkeys (Pucciarelli et al., 1990; Dressino, 1991; Pucciarelli and Dressino, 1996). The components that show greater and/or later growth rates are more affected by malnutrition than those with early and/or shorter growth spans. Early malnutrition in rats diminished brain weight and consequently, the size of the braincase was lesser (Pucciarelli and Oyhenart, 1987). In monkeys (Pucciarelli et al., 1990; Dressino, 1991), the middle neural component was more affected than the rest of the braincase. This can be explained by an arrest in masticatory length, which in turn obeyed muscle underdevelopment due to malnutrition.

Form (i.e., size plus shape) changes found in the present experiment partially agreed with the orthocephalization process described for *Saimiri* (Pucciarelli and Dressino, 1996), in which reduction in size only was evoked by malnutrition. Shape changes, however, may be demonstrated by other means. One of them was the differential arrest in growth seen for the minor functional cranial components. Similar effects were shown in a cross-sectional experiment made on control and malnourished squirrel monkeys (Pucciarelli et al., 1990), in which the masticatory and optic components grew less than the



rest of the face, while the middle neural component grew more than the rest of the neurocranium.

### CONCLUSIONS

1a. Facial growth was, in general terms, greater than neurocranial growth in the weanling *Saimiri*. Components grew in the following decreasing order: masticatory, middle neural, optic, and respiratory. The anterior and posterior neural components followed similar low-patterned growths.

1b. The optic pattern of growth was dissimilar to that of the anterior neural component although a functional relationship exists between capsular matrices and the topographic neighborhood of both cavities.

1c. The posterior neural component showed a growth pattern similar to that of the anterior neural one. This is related to the highly growing cerebellum and other posterior neural structures.

2a. Malnutrition acted mainly on face and secondarily on the neurocranium. This affected size, and shape changes were also inferred.

2b. Nutritional stress delayed growth in the masticatory, respiratory, optic, and middle neural components, depending on the length and/or lateness of onset of their respective growth spans. The anterior and posterior neurocranial components remained stable because they are related to earlier and/or shorter growth spans.

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